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ANTARCTIC OZONE CHANGE CORRELATED TO THE STRATOSPHERIC TEMPERATURE FIELD AND THE SOLAR ACTIVITY

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Abstract: Data of total ozone obtained by the ground-based measurements (Dobson spectrophotometer) at Japanese Antarctic Station, Syowa (69°00′S, 39°35′E), are analysed together with data of stratospheric temperature at the same site. The period of analysis is 21 years from 1966 to 1986, covering almost two solar cycles. The time series of monthly averages of the both quantities for October, November and December is compared with the time series of the relative sunspot numbers. A relatively high correlation is found between the relative sunspot number, and the total ozone and the stratospheric temperature at Syowa for the 21-year period inclusive.

A peak negative correlation with respect to the present-day 11-year sunspot cycle is found at a lag of 3 years of ozone (or temperature) relative to the sunspots. This result will be discussed in connection with the results obtained by H. C. WILLETT (J. Geophys. Res., **67**, 661, 1962) and H. C. WILLETT and J. PROHASKA (J. Atmos. Sci., **22**, 493, 1965).

1. Introduction

SEKIGUCHI (1986) analysed the total ozone and the stratospheric temperature at the Japanese Antarctic Station, Syowa, and showed a very high correlation between these two quantities during the spring season. He also suggested a positive correlation between ozone (and temperature) and the solar activity.

WILLETT (1962) presented certain statistical evidence of significant relationship between ozone and the solar activity as represented by the relative sunspot number. He concluded that the highest negative correlation between ozone and sunspots is found at a lag of one and a half years of the sunspot relative to ozone. He suggested the effect of the direct insolation on the ozone balance in order to explain the existence of the correlation between ozone and sunspots.

His study was widely debated because the data of total ozone he used were geographically and chronologically spotty. WILLETT and PROHASKA (1965) found, however, the same relationship with little reduction of significance in the data of relatively complete records of the only two stations (Arosa and Tromosö), and in the calendar seasonal and even monthly data.

2. Correlation between the Monthly Mean Amount of Total Ozone at Syowa and the Relative Sunspot Number

Table 1 contains the monthly averages of total ozone ($\bar{\Omega}$) and 100-mb temperature

Table 1. Relative sunspot number, and monthly mean value of total ozone and temperature at 100-mb level at Syowa Station.

Year	Sunspot number	Monthly mean ozone (in Dobson unit)			Monthly mean temperature (°C)		
		October	November	December	October	November	December
1954	4						
55	38						
56	142						
57	190						
58	185						
59	159						
60	112						
61	54						
62	38						
63	28						
64	10						
65	15						
66	47	360	397	349	−64.6	−47.6	−39.8
67	94	377	378	355	−61.1	−47.5	−40.5
68	106	381	439	379	−65.6	−39.0	−40.1
69	106	308	338	346	−72.0	−57.7	−43.6
70	105	297	376	350	−70.1	−50.0	−43.2
71	67	332	385	314	−67.7	−46.6	−43.3
72	69	328	382	352	−66.9	−47.9	−42.4
73	38	*	*	*	−69.4	−56.4	−41.9
74	35	351	409	382	−65.4	−47.7	−41.1
75	15	322	392	374	−67.9	−50.4	−42.1
76	13	284	375	342	−71.2	−50.7	−43.7
77	28	382	363	388	−64.8	−53.6	−40.8
78	93	325	370	358	−67.2	−50.6	−41.8
79	155	387	376	350	−61.0	−48.9	−41.2
80	153	292	352	359	−69.5	−55.7	−42.1
81	141	329	320	341	−65.9	−56.8	−42.8
82	116	236	362	342	−72.9	−51.8	−44.4
83	67	258	307	339	−71.8	−57.6	−43.2
84	46	253	291	325	−70.0	−60.4	−46.9
85	18	207	241	295	−75.6	−65.9	−48.2
86	(13)	(287)	(282)	(313)	−68.3	−62.7	−49.2

*: No observation
( ): Provisional values

($\bar{T}$) at Syowa for three months of October, November and December, together with the annual mean number of sunspots ($\bar{S}$). The measurement of total ozone had started in 1961 at Syowa but it was interrupted between 1962 and 1965. The measurement has been resumed since 1966 excet for 1973. The correlation coefficients between the total ozone and the relative sunspot number are evaluated, using the data in Table 1. The 20-year data of $\bar{\Omega}$ are utilized to evaluate the $\bar{\Omega}-\bar{S}$ correlation coefficients with lags of -12 to $+1$ years of $\bar{\Omega}$ relative to sunspots.

The correlation coefficients between $\bar{S}$ and $\bar{\Omega}$ are shown in Fig. 1. A peak negative correlation with respect to the present 11-year sunspot cycle ($R=-0.70$) is found

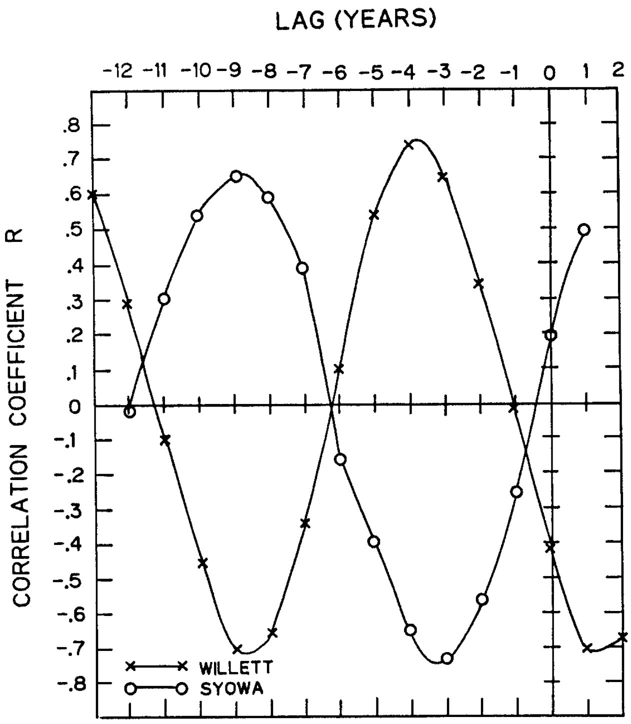

Fig. 1. Correlation of monthly mean (October) total ozone at Syowa Station ($\bar{\Omega}$) with number of sunspot ($\bar{S}$). The result by WILLETT (1962) is shown for comparison.

at a lag of three years of the ozone relative to the sunspot number (the maximum of ozone occurs 3 years before the maximum of the sunspot number). In the same figure are shown the correlation between the worldwide average of the total ozone and sunspots for comparison, which was obtained by WILLETT (1962). His result indicates a highly negative correlation ($R=-0.70$) being found at a lag of 1.5 to 2 years of the sunspots relative to zone. WILLETT and PROHASKA (1965) has shown that the correlation between $\bar{S}$ and $\bar{\Omega}$ at single stations (Arosa and Tromosö) has the characteristics similar but with a small phase difference to his previous results. These results suggest that the relationship between $\bar{S}$ and $\bar{\Omega}$ in Antarctica might be different from that between $\bar{S}$ and $\bar{\Omega}$ in the middle latitudes.

3. Correlation between Stratospheric Temperature and Ozone

The present author presented a high correlation between $\bar{\Omega}$ and $\bar{T}$ (monthly mean temperature in the lower stratosphere) (SEKIGUCHI, 1986). The result is summarized in Table 2. The high correlation between $\bar{\Omega}$ and $\bar{T}$ (especially in October and November) promises the high correlation between $\bar{S}$ and $\bar{T}$ in the lower stratosphere, which can be seen in Fig. 2.

4. Discussion

The high correlation between $\bar{\Omega}$ and $\bar{S}$, such as that indicated in the previous section, might be explained either by a direct insolation effect on the ozone balance

Table 2. Correlation coefficients between $\bar{\Omega}$ and T.

Level	October	November	December
300 mb	0.48	0.70	0.20
250	0.60	0.75	0.22
200	0.73	0.78	0.31
175	0.79	0.81	0.34
150	0.87	0.88	0.41
125	0.90	0.93	0.54
100	0.92	0.96	0.72
70	0.90	0.96	0.68
50	0.83	0.92	0.64
40	0.77	0.82	0.57
30	0.70	0.60	0.52

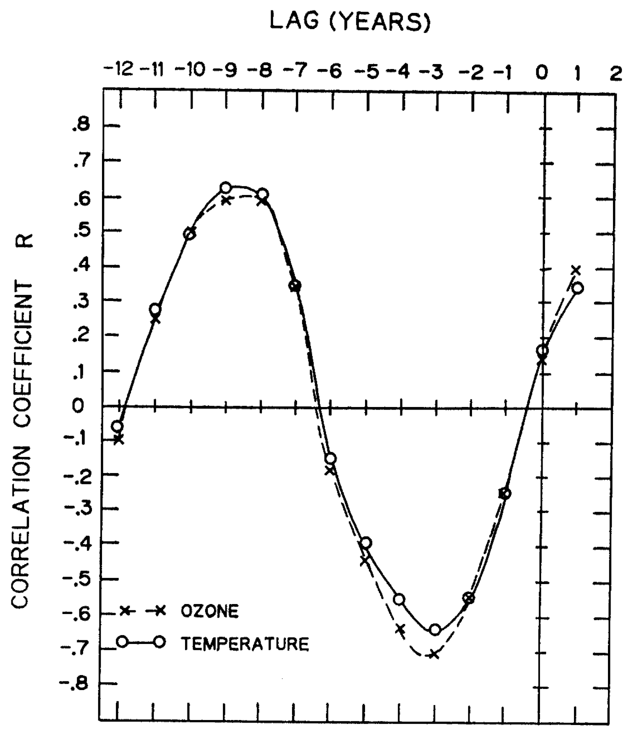

Fig. 2. Correlation of three-month mean 100-mb temperature (October, November and December) at Syowa Station with number of sunspots (solid line). The result of $\bar{\Omega}-\bar{S}$ correlation for the same period is shown for comparison (dashed line).

in the ozonosphere, or by an indirect large-scale insolation effect on the stratospheric circulation around the Antarctic region.

Willett (1962) insists that, as far as the global aspect of ozone distribution is concerned, the primary explanation must be looked for in an insolation effect, presumably in the spectral distribution of insolation energy in the ultraviolet, because we can not find any correspondingly significant and consistent correlation between sunspots and atmospheric circulation.

Penner and Chang (1978) calculated the possible ozone variation related to the 11-year solar cycle, using data of the most reasonable variation in the solar UV flux at that time. They concluded that the ozone record as published by ANGELL and KORSHOVER (1978) is apparently consistent with solar flux variations of the magnitude used in their study. The amplitude of total ozone variation derived from the assumed variation of solar UV flux in their study was less than $\pm 4\%$ of the global mean total ozone amount. This magnitude is too small for explaining the so-called ozone hole in the Antarctic region, since the amount of ozone decrease in the Antarctic attained to more than 40% (October 1985) of the "climatic" average (the mean value of $\bar{\Omega}$ for 1966–1979) at Syowa. Such a large amount of ozone depletion could not be explained by the model of PENNER and CHANG (1978).

Recently CALLIS and NATARAJAN (1986) developed a photochemical model for explaining the Antarctic ozone depletion, which suggests that the ozone loss is principally due to catalytic destruction of ozone by high levels of total odd nitrogen. Further they concluded that these odd nitrogen species would be increased due to enhanced downward transport from the mesoshere and would be thought to be associated with the 11-year solar cycle. They predicted that the ozone hole would be most pronounced 7.5 to 9 years after a solar minimum (presumably in 1986). The phase difference between the Antarctic ozone depletion and the solar cycle suggested by CALLIS and NATARAJAN (1986) seems to be a little different from the actual phase relation between the two quantities. The ozone hole seems to be most predominent in 1985, as far as the ozone record at Syowa is concerned; $\bar{\Omega}$ from October to December in 1986 were larger than those in 1985. Further the TOMS data of Nimbus 7 has shown the decay of the ozone hole phenomena in the 1986 spring compared with the 1985 spring (KRUEGER *et al.*, 1987).

In order to presume the existence of relationship between the 11-year solar cycle and the Antarctic ozone variation, as shown in Fig. 1, we need a much longer period of ozone observation in the Antarctic, covering years of several solar cycles. At the present stage, available information on ozone, solar UV flux and stratospheric circulation is limited. Therefore, it would be very difficult to get a concrete image of the

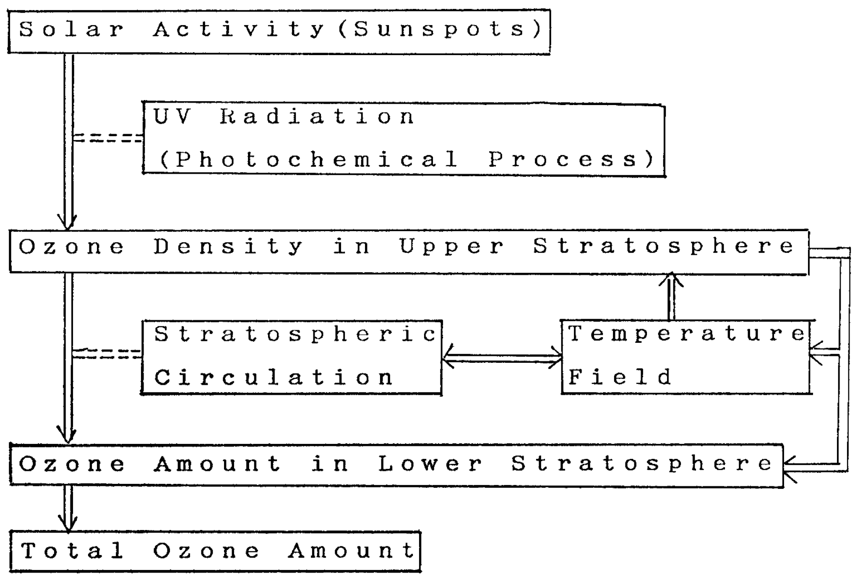

Fig. 3. Process governing the ozone depletion in the Antarctic.

relation between $\bar{S}$ and $\bar{\Omega}$. Nevertheless, the present author dares to emphasize the indirect influence of the solar activity on the variation of $\bar{\Omega}$, by the following chain reactions: The change of UV flux in the solar radiation would induce the change of ozone density especially in the upper stratosphere, resulting in the change of temperature field there. The change of the temperature field might give rise to the three-dimensional change in the stratospheric circulation. The change in the stratospheric circulation would cause the change in the ozone density as well as in the temperature in the lower stratosphere. The high correlation between $\bar{\Omega}$ and $\bar{T}$ as shown in Table 2 suggests that the stratospheric circulation around Antarctica in recent years should have an area of abnormally strong upward motion, which coincides with the ozone depletion area. The scenario of the process governing the ozone depletion in the Antarctic is shown in Fig. 3.

The existence of the vertical circulation, affecting ozone distribution in the Antarctic stratosphere was studied by YAMAZAKI (1987a, b). In this connection, a real evidence of the relation between the solar activity and the stratospheric circulation in the Antarctic region would be the subject for future research.

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